Designing of a High Voltage DC Power Supply

Rahul Deb and Diganta Kumar Sarma#

Department of Physics, B. Borooah College, Ulubari, Guwahati-7, Assam, India

#E-mail address: sarma.diganta@gmail.com

Abstract

An assembly of three simple circuits to construct a high voltage dc power supply has been studied. The different circuits employed in the entire device are - 1) A regulated power supply, 2) A 555 timer circuit & 3) A power amplifier circuit. It has the capacity to discharge a vacuum tube and gas filled tubes. Here a flyback transformer has been used which provides a high dc voltage with saw-tooth waveform. The device is a better alternative for induction-coils used as high voltage source in discharging gas filled tubes. Apart from these the device also has the provision to work both under alternating and direct current, a part of the device can also be used as an astable multivibrator. Overall expense for the construction of the device is low and hence it is economically viable too.

1. Introduction

Charged particle accelerators have played the most crucial role in the development of nuclear physics. One of the types of particle accelerator is the electrostatic accelerator, now these require a high voltage generator or power supply. To generate high voltage was one of the first needs to pursue many scientific experiments especially in atomic and nuclear science. The oldest known types of electrostatic accelerators that are still in use are the Cockroft Walton generator and the Van de Graaff generator. Over the ages the Van de Graaff generator has undergone certain changes and is now known as Pelletron. The issue with these types of generator is that safe distance is required to operate them as they have the capacity to ionize the surrounding up to a certain distance. These generators can generate voltages up to a few million volts. These two generators have been described precisely below.

1.1. Cockroft-Walton generator (Voltage multiplier):

It is a circuit comprising of a step up transformer connected to an array of diodes and capacitors. In this circuit the diodes conduct alternately and charge up the capacitor. The final voltage is taken across a line of capacitors connected in series in the multiplier circuit which serves as a number of batteries connected in series [1].

1.2. Van de Graaff generator:

It is basically a static charge accumulating device. In this device a rotating belt continuously gathers charge from a point and deposits it on a metallic dome increasing the potential of the dome and hence high voltage is obtained. These high voltage devices mostly find their applications in scientific laboratories as particle accelerators. These were the earliest methods of high voltage generation and by now these devices have undertaken many modifications. The modified version of the Van de Graaff generator is the Pelletron [2].
The primary objective of the present work is to design a high voltage generator using an assembly of timer, transistor and transformer as a substitute for induction coil to use in undergraduate laboratories for experiments where high voltage DC power supply is required.

2. Experimental Details

The methodology to generate a d.c voltage of the order of 20KV includes the use of a step down transformer along with a 555 timer, a 7812 voltage regulator, a 2N3055 transistor and a flyback transformer.

Using a step down transformer along with diodes a fully rectified power supply is made. The output is filtered using capacitors. This output is fed to a 7812 regulator for a regulated voltage. This regulated voltage is used for the 555 timer setup designed to work as an astable multivibrator. The output of the multivibrator is fed to the base of the power transistor. The emitter is grounded and the collector is positively biased through the primary of the flyback transformer. The output in the form of high voltage is obtained across the secondary of the flyback transformer. The output voltage can be regulated by regulating the frequency of the 555 timer circuit using a potentiometer in the multivibrator circuit.

2.1. The Power Supply Circuit:

The ac voltage is connected to a transformer which steps down the ac to the level for the desired dc output. A diode rectifier then provides a full wave rectified voltage which is initially filtered by a simple capacitor to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation. A regulator circuit can use this dc input to provide a dc voltage that not only has much less ripple voltage, but also remains the same dc voltage even if the dc voltage varies somewhat or the load connected to the output dc voltage changes. For this voltage regulation we have taken the help of IC units. Here a 7812 IC has been used which provides a regulated voltage of 12V. The output voltage is fed to the supply terminal of the 555 timer IC. The circuit diagram of the power supply circuit depicting the use of an IC 7812 is shown in Fig. 1.

2.2. 555 Timer as Astable Multivibrator:

The astable multivibrator generates a rectangular wave, the period of which is determined by the circuit external to IC 555. The astable multivibrator does not require any external trigger to change the state of the output, hence the name free running oscillator. The time during which the output is either high or low is determined by the two resistors and a capacitor that are externally connected to the 555 timer. The circuit diagram for the timer assembly is shown in the Fig. 2.

2.3. The Power Transistor:

The 2N3055 is a silicon epitaxial-base NPN transistor in Jedec TO-3 metal case [3]. It is intended for power switching circuits, series and shunt regulators, output stages and high fidelity amplifiers. The output of the timer circuit is applied to the base of the transistor through a resistor so as to stabilize the power content of the input signal of the transistor. The transistor increases the power content of the signal and apply this signal to the primary of the flyback transformer which induces the voltage and thus we obtain the high D.C voltage.

2.4. Flyback Transformer:

A flyback transformer (FBT), also called a line output transformer (LOPT), is a special type of electrical transformer. It was initially designed to generate high current sawtooth signals at a relatively high frequency. In modern applications it is used extensively in switched-mode power supplies for both low (3V) and high voltage (over 10 kV) supplies [4]. It was invented as a means of controlling the horizontal movement of the electron beam in a cathode ray tube (CRT). Unlike conventional transformers, a flyback transformer is not fed with a signal of the same wave shape as the intended output current. Unlike a power transformer which uses an alternating current of 50 or 60 Hz, a flyback transformer typically operates with switched currents at much higher frequencies in the range of 15 kHz to 50 kHz. It is a modified form of an ordinarily available step up transformer. It has a number of primaries with a single secondary. The output of this transformer is in D.C as the A.C signal is internally rectified using diodes within the
transformer. This transformer finds its use in computers and other devices having pictures tubes with high voltage requirement.

3. Results and Discussions

The device designed can generate sparks up to a length of 0.8 cm, as to generate a spark of 1 cm length a voltage of nearly 30 kV is required so it suggests that the voltage generated by our device is around 20 kV [5]. Thus it is capable of easily discharging H₂, He, Ne, Ar filled gas tubes and has been tested in the laboratory. If the transformer used in the power supply is replaced by a transformer with higher current ratings the length of the spark developed indicates that the voltage developed is even higher. The complete circuit diagram for the high voltage power supply is shown in the Fig. 3.

![Circuit diagram of the High Voltage Power Supply](image)

Fig. 3: Circuit diagram of the High Voltage Power Supply

3.1. The Power Amplification

The power transistor is used in the CE mode as this mode has the ability to give the maximum current and voltage amplification. This configuration is best suited for voltage, current and power gains, also the input and the output resistances of the CE mode lies between that of CB and CC mode [6]. The transistor is biased in the simplest configuration to avoid any complication that may arise due the various components used in the circuit.

3.2. Principle of operation of flyback transformer

Flyback circuits repeat a cycle of two or three stages; a charging stage, a discharging stage, and in some applications idle time following a complete discharge. Charging creates a magnetic field. The discharging action results from the collapse of the magnetic field.

**Charging Stage:** When the flyback transformer draws current from the power source, the current increases. This current flow creates a magnetic field flux that also increases. Energy is stored within the magnetic field. The associated positive flux change induces a voltage in the transformer which opposes the source voltage. Typically, a diode and a capacitor are series connected across the transformer winding. A load resistor is then connected across the capacitor. The diode is oriented to block current flow from the flyback transformer to the capacitor and the load resistor during the charging stage. Controlling the duty cycle the amount of energy stored during each cycle can be controlled.

**Discharge Stage:** The current from the source is then interrupted by opening a switch, thereby causing the magnetic field to collapse or decrease, hence a reversal in the direction of the magnetic field flux change. The negative flux change induces a voltage in the opposite direction from that induced during the charging stage. The reversed induced voltage(s) tries to create a current flow. The open switch prevents current from flowing through the power supply. With the voltage reversed, the diode now permits current flow through it, hence current flows into the capacitor and the load across the capacitor. If the current can flow, then the resulting flow of current is in the
direction, which tries to maintain the existing magnetic field. The induced current cannot maintain this field but does slow down the decline of the magnetic field. A slower decline translates to a lower induced flyback voltage. If current cannot flow, the magnetic field will decline very rapidly and consequently create a much higher induced voltage. This principle, along with controlling the duration of the charging stage, allows a flyback inductor to increase or decrease the voltage without the use of a step-up or step-down turn ratio.

Idle Stage: This stage occurs whenever the flyback transformer has completely discharged its stored energy. Input and output current is at zero value.

4. Conclusions

The high voltage power supply so designed is capable of ionizing air kept at a distance of about 0.8cm. When the power supply is connected to the discharge tube it easily discharges it and when experiment is carried out with a grating a well resolved spectrum is observed. Hence it easily finds its way in a lab.

The power supply has certain advantages —
1. As the circuit itself has a frequency generator it is independent of the power source. When a dc source is used the power supply designed will be substituted by a battery or a battery eliminator.
2. The device without the final amplification and the flyback transformer serves as a frequency generator with a provision of changing the frequency also with the introduction of a variable resistor the amplitude of the wave can be varied.
3. As the voltage generated is around 20KV so the safe distance of operation of the device is very small i.e. the minimum distance that should be maintained during its operation.
4. The device so designed is simple in construction and is made from components that are easily available in the market.
5. The components used in the setup are not too expensive hence the device is economically viable too.

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6. References